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Annual Performance Report

for

Analyses of Plasma Measurements

With the Comprehensive Plasma Instrumentation (CPI)

for the Geotail Mission

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Period Covered: 1 October 1995 – 30 September 1996

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Introduction

The Comprehensive Plasma Instrumentation (CPI) on board the Geotail spacecraft provides observations of the charged particles that comprise the plasma populations of the magnetosphere and the solar wind. Along with observations from other fields and particles instrumentation on Geotail the measurements from CPI provide a fundamental in-situ experimental base for investigations of solar-terrestrial plasmas and fields. Due to the sophistication of the instrumentation the measurements acquired by Geotail represent a real advancement over those from previous magnetospheric spacecraft missions. A significant body of literature based on the Geotail observations has developed since launch in August 1992, and this literature is a measure of the success of the mission to date.

The Comprehensive Plasma Instrumentation for the Geotail mission has been in essentially continuous operation since October 1992. This instrumentation successfully returned high-resolution measurements of magnetospheric and interplanetary plasmas throughout the deep-tail phase of the Geotail mission that ended in December 1994. The near-Earth survey is now in progress.

The CPI continues to provide extremely high-quality observations of plasmas in Earth's magnetotail and magnetosheath and within the solar wind. The twelve sensors in the Solar Wind (SW) analyzer, the five sensors in the Ion Composition (IC) analyzer and the nine ion sensors in the Hot Plasma (HP) analyzer are fully operational. The gain degradation for the above sensors has been minimal and these sensors should be usable for at least ten more years. Seven of the nine electron sensors in the HP analyzer are operating in the same excellent status as the above ion sensors. The other two electron sensors have degraded more rapidly. One of these two sensors is operational without gain degradation for at least 95% of continuous telemetry coverage. This degradation for the two sensors can be overcome by increasing the bias high voltage but the remaining seven sensors are adequate to fully characterize the electron velocity distributions. In addition a change in the bias high voltage would demand an extensive recalibration of all sensors in the HP analyzer. On the basis of the above past performance the CPI is anticipated to be able to supply robust, comprehensive plasma measurements for another ten years.

The plasma measurements from CPI are currently used to support research projects initiated by members of the PI team at the University of Iowa and are distributed to other ISTP scientists in support of various investigations. This report provides an overview of efforts by the CPI PI team during the period 1 October 1995 through 30 September 1996. A list of publications and presentations is appended.

Data Processing

In many cases the physical processes that contribute to the flow of energy and mass through the solar-terrestrial plasma system can be understood only by a detailed examination and analysis of the distribution of particle velocities in the ambient plasmas. The Comprehensive Plasma Instrumentation provides detailed measurements of these distributions. To achieve the resolution required to fully characterize the plasma velocity distributions in the different regions traversed by the Geotail spacecraft the Comprehensive

Plasma Instrumentation employs three plasma analyzers: (1) a Hot Plasma analyzer (CPI-HP) for hot electrons and ions found in the plasma sheet and the inner magnetosphere, (2) a Solar Wind analyzer (CPI-SW) for cool plasmas with high bulk speeds such as those found in the solar wind and the magnetosheath, and (3) an Ion Composition analyzer (CPI-IC) for identification of ion species such as H^+, He^+, He^{++}, and O^+.

The CPI telemetry stream consists of engineering data used to monitor the status of the instrumentation plus responses from the 35 sensors incorporated in the instrumentation. This telemetry is received at the University of Iowa on compact disks provided by the Central Data Handling Facility (CDHF) at Goddard Space Flight Center. Instrument calibrations and algorithms developed by the PI team are used to process the telemetry and produce computer files and graphical output suitable for scientific analyses. In plasma physics the distribution of particle velocities is a fundamental quantity. These distributions can be quite complex. The sensor responses from CPI comprise a record of the plasma velocity distributions near the spacecraft. The CPI-HP analyzer provides complete sets of energy-angle samples for the electron and ion velocity distributions approximately three times each minute. The electron and ion distributions are each sampled at 3456 points in velocity space. The CPI-SW analyzer acquires 8064 samples of the ion velocity distributions repeated approximately every 48 s.

An initial step in the processing is the production of Energy-time spectrograms that display the measured particle intensities as a function of energy, direction, and time in formats sufficiently condensed so that it is possible to obtain an overview of the state of the plasmas without being overwhelmed by the sheer number of measurements. These spectrograms are an invaluable tool for initial surveys of the plasma environments encountered by the spacecraft. Complete spectrogram sets for the CPI-SW and CPI-HP analyzers are maintained in hardcopy form at the University of Iowa. One complete set of CPI-HP spectrograms is also provided for use by the Geotail EPIC PI team. This set is used as a primary tool for the identification of plasma regions encountered by the Geotail spacecraft. The EPIC team uses the region identifications for classification of their own energetic particle measurements and apply this classification in statistical analyses of the EPIC data. Several reports based on this work were presented at the 1995 Fall Meeting and the 1996 Spring Meeting of the American Geophysical Union (AGU). A publication that describes the work is in preparation [Eastman et al., 1996]. When the region identifications are complete they are to be made available by the EPIC PI team for use by other ISTP investigations. A preliminary list is maintained as a file on a computer at Johns Hopkins University/Applied Physics Laboratory, and information regarding access can be obtained from Stuart Nylund (e-mail stuart.nylund@jhuapl.edu).

The CPI-SW and CPI-HP measurements are also used to compute plasma parameters that provide a summary account of the state of the plasmas. These plasma parameters include, but are not limited to, the plasma number density (particles/cm^3), the bulk-flow velocity (km/s), and the temperatures of ions and electrons (K). To maintain the high quality of these parameters instrument calibrations are periodically reviewed and updated. Revised calibrations are incorporated in the computational algorithms used to compute parameter files at the University of Iowa. In addition, a similar set of software is provided by the PI team to the CDHF for computation of parameters that are included in the CPI Key Parameter files available to ISTP investigations. The software provided to the CDHF is designed to compute robust good-quality parameters but uses only a subset of the possible detectors so that the results will be insensitive to small variations of instrument calibrations. Thus the parameters can be made available to the research community in a timely fashion.

Since January 1995 both spectrograms and plasma parameters have also been made more generally available in convenient graphical formats on the World Wide Web. Access is unrestricted and can be gained using conventional web-browsing software. The web data reside on a computer at the University of Iowa, and URL http://www-pi.physics.uiowa.edu/ points to the site.

The spectrograms and plasma parameters are produced routinely for all available data. Other analysis products are produced on a campaign basis, i.e., as needed to support various individual investigations, and the development of analysis algorithms and software is an ongoing process. Specialized products include two dimensional cuts through individual particle velocity distributions, particle pitch-angle distributions computed from a combined set of plasma data and magnetic field data provided by the Geotail MGF PI team, specialized moments including those that utilize magnetic field data e.g., total pressure (magnetic plus particle) and plasma beta, and moments computed for limited sets of energies and directions. The development of these specialized products is frequently dependent on the requirements of a particular investigation.

Research Efforts

The Geotail Mission was designed with two distinct phases. The first, a survey of the distant magnetotail to distances as large as 210 Earth radii (R_e), was completed in December 1994. Although the observational sequences for this distant-tail survey are complete, the analysis of the observations is ongoing. The second phase of the Geotail Mission is a survey of the relatively nearby tail at distances 10 to 30 R_e, and this survey is now in progress. To date, the CPI PI team has contributed to a total of 32 publications and for the time period of this report 39 presentations at scientific meetings and symposia. The remainder of this report consists of brief descriptions of several of the research investigations that are now in progress.

When the cold solar-wind plasmas that stream outward from the sun cross the bow shock that stands ahead of the terrestrial magnetosphere these plasmas are both heated and deflected. This effect is most pronounced near the nose of the magnetosphere where the shocked magnetosheath plasmas are found to be nearly stagnant and have temperatures substantially higher than the temperatures found in the undisturbed solar wind. Farther downstream the effect is less, but when magnetosheath plasmas there are compared with plasmas ahead of the shock the deflection and the heating are still clearly discerned. It is anticipated that somewhere downstream from the shock the magnetosheath plasmas will be eventually assimilated into the solar wind, although it is not clear precisely where and how this will occur. Observations from the Geotail CPI-SW analyzer acquired in the distant magnetosheath on 28 December 1992 may provide insight into the eventual fate of magnetosheath plasmas. On this date the Geotail spacecraft was situated in the magnetotail at a distance from Earth approximately 150 R_e downstream and 30 R_e towards the dawn side of the tail. In a series of measurements acquired between 0300 and 1500 UT the plasmas observed with Geotail appear to have two distinct components. There is a hot streaming component that is typical of the shocked magnetosheath, but mixed with this plasma is a much colder component also streaming tailward. In fact, this cold component is found to be very like the undisturbed solar-wind plasmas observed at the same time with the IMP-8 spacecraft which was located in front of the shock. Thus it appears that Geotail observes a mixing of shocked and unshocked plasmas. Without the simultaneous measurements from IMP-8 the interpretation of the Geotail observations would be difficult and results of this study could be ambiguous. These observations are important in determining the mechanism for the assimilation of the hot, shocked plasmas in Earth's bow shock into the cool, downstream solar wind. A manuscript that reports on these observations is currently in preparation and will be submitted for publication in the Journal of Geophysical Research [Frank et al., 1996].

The existence of an extended magnetotail downstream from Earth was first reported by Ness [J. Geophys. Res., 70, 1965] based on observations of a stretched tail-like configuration of magnetic fields observed behind Earth with a magnetometer on board the IMP-1 spacecraft. These magnetic fields can only be supported if there are electric currents that flow across the midplane of the magnetotail carried by plasmas confined to a plasma sheet that extends across the width of the tail. Cold plasmas from the solar wind or the ionosphere that enter the distant tail are accelerated and heated due to interactions with the electric fields near the midplane of the tail. Much of this plasma is then transported towards Earth to populate the near-Earth plasma sheet. There is extensive theoretical work to show that the initial processes of acceleration in the distant tail will produce complex recognizable signatures in the velocity distributions of the particles. The cold plasmas from the solar wind and the complex accelerated distributions near the site of the acceleration were both observed frequently with the CPI-HP analyzer during the deep-tail phase of the Geotail mission. The analysis of these measurements remains an active area of research for the CPI PI team. In addition, recent work based on theory and computer simulations suggests that the ion velocity distributions near Earth may retain a "memory" of the processes that occur deep in the tail. This is in stark contrast to previous theories that assumed the distribution of velocities would become random and featureless in a short period of time. Thus it is possible that the plasma-sheet ions observed near Earth with the CPI-HP analyzer may provide important insight into physical processes that operate at large distances. Complex ion velocity distributions observed with Geotail in the plasma sheet near Earth are reported in a recent publication [Frank et al., 1996]. These ion velocity distributions appear to display the "memory" effects predicted by recent theory. The measurements also indicate the presence of cold electrons and cold ion beams streaming out of the low-altitude ionosphere. The ion beams may be the source for the very energetic particles observed with high-energy particle detectors such as the Geotail EPIC instrumentation. The mechanisms responsible for accelerating ionospheric ions to very high energies in the magnetosphere are not well understood. The ions observed with the CPI-HP analyzer appear to have gained substantial energy already as they exit the ionosphere, and this initial acceleration at low altitudes may be an important step in the production of very high energy ions.

The currents carried by plasma sheet particles in the magnetotail are part of a system of currents that connects to the auroral regions of the ionosphere at altitudes approximately

100 km above Earth. A disruption of the plasma–sheet currents across the tail is thought to play an important role in magnetospheric substorms. Substorms are responsible for the spectacular visual display of the Northern Lights, but substorm activity also interferes with radio communication and in extreme cases can cause severe damage to man–made power grids. Disruption of the plasma–sheet currents could be caused by changes in the flow of the solar wind and interplanetary magnetic fields that impinge on the magnetosphere and provide much of the energy that drives the solar–terrestrial plasma system. Reliable prediction of substorm effects requires space–based monitors and a theoretical framework that relates cause and effect relationships in the solar wind, the magnetosphere, and the low–altitude ionosphere. At present, the physical processes that control current flow in the magnetosphere are not well established. The theories require the guidance and constraints that can only be provided by detailed observations of the actual plasmas and fields in the various interconnected regions. The present series of Geotail orbits carries the spacecraft through the plasma sheet at distances 10 to 30 R_e from Earth. This spans the region of the tail that is thought to be most important for the development of substorms. Magnetotail currents must exist to support the configuration of magnetic fields that is found in the magnetotail. However, direct detection of currents with plasma instrumentation has proven difficult. Electric currents in a plasma are usually due to small differences in the motions of the positively charged ion and the negative electron components of the plasma. These currents flow through very large regions, often one or more Earth radii across. Thus, the total current can be enormous even though the current per unit area may be quite small and difficult to detect. The CPI–HP analyzer has demonstrated the capability to make direct measurements of the differences in electron and ion velocities in some magnetotail current systems [Frank et al. 1994]. Observations of the plasmas can also provide indirect evidence of currents by measuring stresses in the magnetotail system that are responsible for driving the currents. The search for evidence of current systems in the near–Earth magnetotail is an active area of research for the CPI PI team. An initial report on this work was given at the Fall Meeting of the American Geophysical Union in December 1995. Additional reports have been given at the Third International Conference on Substorms, the Spring Meeting of the American Geophysical Union and the 31st Scientific Assembly of COSPAR. The titles and author lists for these reports are given in the list of presentations included with this report.

GEOTAIL PUBLICATIONS AND PRESENTATIONS

PUBLICATIONS

1. Frank, L. A., K. L. Ackerson, W. R. Paterson, J. A. Lee, M. R. English and G. L. Pickett, The Comprehensive Plasma Instrumentation (CPI) for the Geotail Spacecraft, J. Geomag. and Geoelectr., 46, 23-37, 1994.

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Presentations at the Third GEOTAIL Workshop at the Institute of Space and Astronautical Science (ISAS), Kanagawa, Japan, October 1995.

1. Christon, S. P., G. Gloeckler, T. E. Eastman, R. W. McEntire, E. C. Roelof, A. T. Y. Lui, D. J. Williams, L. A. Frank, W. R. Paterson, S. Kokubun, H. Matsumoto, H. Kojima, T. Mukai, Y. Saito and T. Yamamoto, Energetic Ion Charge State and Species Composition Variation With Downtail Distances in Various Magnetotail Regions, presented at the Third Geotail Workshop, Institute of Space and Astronautical Science, Sagamihara, Kanagawa, Japan, 23–25 October 1995.

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